CHANGES TO THE ETA FORECAST SYSTEMS

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1. INTRODUCTION

A set of changes is being introduced into the early and Meso Eta systems which affects its data assimilation system (the EDAS), the forecast model, and the post-processing. The desirability of and/or need for these changes has grown quickly so that individual parallel tests of each of the many separate modifications was not feasible. This is not to say that each change was not tested individually, but rather that a full-blown parallel test may not have been possible. The changes to the assimilation and forecast model are described in Section 2, changes to the Eta post-processor are covered in Section 3, and an assessment of their impact as determined from a set of parallel forecasts is provided in Section 4.

2. CHANGES AFFECTING THE ASSIMILATION CYCLE AND FORECAST

Since the EDAS involves the running of a series of short Eta Model forecasts (only one 3-hour forecast in the case of the Meso Eta), any change incorporated into the forecast model will also necessarily affect the data assimilation and its evolution. The modifications in the soil package will be considered first since one change in it strictly affects only the assimilation cycle.

2.1 Soil Package

1. The first guess for the value of the soil moisture at the beginning of the EDAS is taken from the Global Data Assimilation System (GDAS). When compared against certain observations (e.g. monthly total precipitation), it was shown that the soil moisture in the GDAS was typically too large. In the new version, large values of GDAS soil moisture are reduced if they exceed a particular threshold and they are never allowed to exceed a maximum value.

2. One of the specified fields in the soil package is the so-called green fraction which indicates the fraction of an area that is covered by green vegetation each month of the year. In the former version, this field was

taken from a NASA dataset that has a 1°x1° resolution and is based on a one-year sample from 1987. The new version uses a NESDIS dataset that has a 0.15°x0.15° resolution and is based on a 5-year sample. The values in the newer data are roughly 10-15% larger than in the older one and this has led to an increase in surface evaporation due to the greater amount of moisture available in the plant leaves through evapotranspiration.

3. One of the factors that determines the amount of evaporation that takes place from bare soil is the amount of water in the soil at that moment. As the amount of soil water drops, so does the evaporation. In the former version, the range of values of soil moisture through which the evaporation changed from large to small was very narrow. Based on recent observations, the new version uses a more gradual transition between large and small evaporation rates as a function of soil moisture.

4. Partitioning of energy during the situation of melting snow has been refined. Snow melts in the model whenever the temperature of the snow surface (T_s) is computed to be greater than 0°C. In the former version, the amount of snow melted was found by using up the energy represented by the difference in temperature between T_s and 0°C and at the same time the amount of evaporation from the snow surface was determined using the T_s (>0°C). The result was that more energy was used than was actually available in the system and most notably the magnitude of the evaporation was too large. In the new corrected version, when T_s is initially found to exceed 0°C, the surface energy balance is used explicitly to determine the amount of evaporation and melting but only after resetting T_s to 0°C since the phase change between ice and liquid water can only take place at that temperature.

5. Three modifications were made to reduce what seemed to be too large values of albedo in the presence of snow on land. First, based on the current literature, the value of the albedo over a pure snow surface was reduced from 0.60 to 0.55. Second, the depth of snow in the model below which the albedo of the snow-free surface begins to be considered was increased from 1 cm to 2 cm. Third, the vegetation fraction has been incorporated into the computation of the albedo such that a larger fraction of the snow albedo value is now used when the vegetation cover is small while a smaller fraction of the snow-free albedo value is used when there is more vegetation cover. The overall effect of these modifications will be somewhat warmer low level air temperatures during the daytime in regions of relatively shallow snow.

2.2 Cloud/Radiation Interaction

Both of the changes made to the current operational explicit cloud scheme (Zhao et al. 1997) are related to the manner in which the clouds interact with the radiation package.

1. Previously the radiation package required cloud information input with respect to only three general levels: low, middle, and high. This meant that the cloud information in all of the model's layers had to be condensed down into just these three levels. In its new form, the radiation scheme is allowed to interact explicitly with the predicted cloud water/ice in each of the model's layers which permits a far more realistic interaction between the clouds and the radiation.

2. The second of the two changes is the use of a new formulation for the so-called ‘cloud fraction’ (CF) that exists in each grid box. CF is an important component in the computations regarding the radiative effects within the atmosphere. Previously, that quantity was defined as

$$CF = 1 - \left[\frac{1-RH}{1-RH_0}\right]^{\frac{1}{2}}$$

   where RH is the relative humidity in the box and RH_0 is a critical value required for large scale condensation (0.75 over land; 0.85 over water). It was determined that this formula led to an underprediction of low level cloud. The new formula is taken from Randall (1995) and is given by

$$CF = RH\left[1 - exp\left(\frac{-1000m}{1-RH}\right)\right]$$

   where m is the cloud water/ice mixing ratio. The new relation leads to a cloud fraction that is more consistent with the moisture field and cloud water/ice content and more low level clouds are presented to the radiation package. Tests have indicated that these two cloud/radiation changes tend to produce slightly cooler daytime maximum temperatures and slightly warmer nighttime minimum temperatures under cloudy conditions.

2.3 Shortwave Radiation

As of the beginning of the convective season in the spring of 1996, some field forecasters noted that there seemed to be excessive warming and drying in the lowest 200-300 mb of the atmosphere over parts of the U.S. A primary reason was found to be excessive shortwave solar radiation reaching the ground which led to an inordinate increase in low level vertical mixing. Three changes were made to the radiation computations to address this problem.

1. Ozone absorbs a significant amount of shortwave radiation in the Earth's atmosphere yet it was discovered that essentially no absorption by ozone was taking place inside the Eta Model. Now the entire column of climatological and seasonally varying ozone is represented in the model along with the appropriate absorption.

2. Previously the Earth's orbit was assumed to be circular (eccentricity of 0) which meant that the solar constant (the total amount of incoming solar radiation intercepted by the Earth at the top of the atmosphere) was taken as a constant. However, the orbit is actually an ellipse with an eccentricity of 0.0167 which means that the Earth is actually 3.4% closer to the sun at perihelion in January than it is at aphelion in July. That difference in distance leads to there being 6.9% more solar energy intercepted by the Earth in January than in July. Using a constant average value for the solar constant in the model meant that it saw somewhat too little solar radiation over North America in winter and somewhat too much in summer. The orbit's eccentricity has now been incorporated into the predictions.

3. In addition to ozone, aerosols also have a significant impact on the amount of radiation reaching the surface due to their absorptive and scattering properties. On advice from the individuals who are developing the radiation package used in the Eta Model, the total energy entering the atmosphere was reduced by 3% in order to simulate the aerosol effects. In the next update of the radiation scheme following this one, aerosols will be accounted for explicitly.

2.4 Other Modifications

1. In order to better simulate the way in which the atmosphere interacts the topography, a form drag scheme has been added (Mesinger, et al. 1996). The scheme creates an effective roughness length that is dependent on the wind direction and on the number and elevation of subgrid terrain obstacles within a grid box. This effective roughness length can be much greater than the analogous value would be over flat terrain and can attain a magnitude of 10 m or more. In individual tests, improved prediction of cyclones on the lee of the Rockies was seen when the effective roughness length was used.

2. An improved positive definite advection scheme for specific humidity and cloud water was introduced. Strong gradients should be handled somewhat better than in the previous scheme.

3. Under conditions of extreme stability, a minimum amount of turbulent mixing had been specified using an exchange coefficient of 0.01 m^2 s^{-1}. Given that the true value of this quantity cannot be determined accurately while at the same time the Eta forecasts have tended to show too cool low level temperatures under such stable situations, the minimum value of the turbulent exchange coefficient under the most stable conditions has been increased to 0.1 m^2 s^{-1} to produce slightly warmer temperatures.

4. Computational efficiency is a critical aspect of any operational model. The Eta Model source code was carefully examined and found to be lacking in vectorization in some sections and in parallelism in many of its parts. The code was optimized and a decrease in wallclock time of a factor of 3 was realized. This optimized code has already been implemented in the Meso Eta and has now become the basis of the Early Eta source code.

3. CHANGES AFFECTING THE POST-PROCESSOR

There are three main areas of changes regarding the post-processor: (1) corrections to the product labels of GRIB and BUFR output to more accurately identify the fields and to bring those labels in line with current WMO standards; (2) addition of new output fields from the soil/surface physics to allow users to examine more quantities from the soil package; (3) miscellaneous changes to add new output fields and to correct errors. Documentation for the GRIB and BUFR formats can be obtained from the NIC (140.90.50.22) via the INTERNET:

ftp://nic.fb4.noaa.gov/pub/nws/nmc/docs/gribed1

ftp://nic.fb4.noaa.gov/pub/nws/nmc/docs/bufrguide.

3.1 Labeling

1. The change in labeling that will likely affect operational users is the change of the GRIB Product Definition Section (PDS) for the so-called "boundary layer" fields which comprise the six lowest layers above the model ground/ocean surface and are each 30 mb deep. These fields are available in the AWIPS output files via the OSO server and in other output files as well. The boundary layer fields are now labeled as PDS level type #116 which indicates a layer between two levels that each are described by their pressure difference with that at the ground. These fields were previously incorrectly labeled as layer type #108 which is a

layer between two sigma levels. (**NOTE:** As of this time, Data Review Group approval has been requested but **not** given for this label change. When authorization is received, these label changes will be made.)

2. Other changes in labeling will not affect operational users as much since those fields are not currently available via the AWIPS output files. The PDS level type for fields on eta surfaces has changed to #119. For native Eta output grids the central latitude and longitude has been added to the end of the Grid Definition Section (GDS); this will help in navigating the native Eta rotated latitude-longitude grids. Turbulent kinetic energy on eta levels is now correctly labeled as being on layer interfaces rather than at midlayers. Cloud water fields now contain only cloud water while cloud ice fields contain only cloud ice. Previously the cloud water fields contained both liquid water and ice. All precipitable water fields now include cloud mixing ratio in the computation.

3. In the hourly station output in BUFR, the tables have been changed to reflect the WMO specification on the number, scale, reference, bit, and unit for each output variable. Also the latitude and longitude of the station is now given as that of the model grid point that is used for the profile rather than the actual latitude/longitude of the station. Finally, variables from the soil surface physics are set to missing for stations over water since those variables are undefined there.

3.2 New soil surface fields

Several new output fields that represent quantities from the soil package are now available via the Eta post-processor.

1. Two-dimensional fields of deep soil temperature (lower boundary condition for the predictive soil layers), surface exchange coefficient, green vegetation cover, volumetric soil moisture and temperature from the midpoints of the two soil layers, total soil moisture, soil moisture availability, ground heat flux, and plant canopy water are now available in GRIB.

2. In BUFR, the surface runoff, underground runoff, accumulated snowfall, surface exchange coefficient, plant canopy water, and the temperature and moisture of each soil layer are available in the set of files called ‘class 1'

3. In the BUFR fields from the files called ‘class 0', the 10-m potential temperature, 10-m specific humidity, and maximum/minimum temperatures were

dropped to make room for the first soil layer temperature, surface evaporation, surface runoff, and snow water equivalent.

3.3 Other changes

In the GRIB files:

1. Cloud ice on pressure surfaces, cloud top temperatures, instantaneous precipitation rate, and snow ratio (the fraction of the cloud-scheme precipitation that is snow) are now available from the explicit cloud scheme in GRIB.

2. Components of radiative fluxes at the surface and top of the atmosphere (longwave up and down, shortwave up and down) are now available separately rather than combined.

3. The snow cover and time-averaged total cloud fraction have been corrected.

4. The albedo and cloud fraction computations in the post-processor are now consistent with those used in the model integration.

In the hourly station output files in BUFR:

1. The calculation of potential evaporation has been corrected.

2. Low, middle, and high cloud fraction as well as the land/sea mask have been added to both classes of BUFR output.

3. The turbulent kinetic energy (interpolated to the middle of the eta layers) has been added to the 'class 1' profiles.

3.4 Computational efficiency

As was done with the forecast model source code, an examination of the post-processor source code was made and significant optimization was effected.

4. RESULTS FROM PARALLEL TESTS

At the beginning of August 1996 the full set of changes described above was placed into a parallel system that was an analog to the current operational Early

Eta. That system was in place until late September. Below is a sample of results that illustrates the effects of the changes to the Eta forecasts.

4.1 Station soundings

As stated earlier, the initial catalyst for creating this set of changes was the observation by some forecasters that the operational Eta forecasts were showing too much low level heating and drying over parts of the U.S. as of the start of the 1996 warm season. Much of this problem was traced to the excessive solar shortwave radiation reaching the ground. Fig. 1 shows both observed and 24-hr forecast soundings from Topeka, Kansas, valid at 0000 UTC 4 September 1996. The forecast sounding at Topeka from the operational Eta (Fig. 1a) shows a well-mixed boundary layer which is warmer and drier than the observed sounding. The forecast sounding from the parallel test with the above changes (Fig. 1b) is closer to the observed temperature/moisture profile. Additionally, the parallel forecast reduced the depth of the mixed layer compared to the operational Eta, with a LCL closer to the observed pressure of 800 mb.

Fig. 2 shows observed and 12-h forecast soundings from Topeka valid at 1200 UTC 4 September 1996. In the operational Eta (Fig. 2a) the excessive boundary layer warming during the previous day has led to a 5°C error in the low-level inversion. This error was significantly reduced in the parallel run (Fig. 2b).

4.2 Precipitation scores

Bias and equitable threat scores for 24-hr precipitation for the entire length of the parallel test are shown in Fig. 3a and 3b. The operational Eta is denoted by circles with '+' and the parallel Eta by the open squares. Details on the computation of these scores can be found in Rogers et al. (1996). The bias score from the parallel Eta was increased at all thresholds, eliminating a slight dry bias at thresholds above 0.01 in. Little change was seen in the equitable threat score implying that on average the areal coverage of forecast precipitation was not changed by the parallel Eta while the amount of precipitation did.

4.3 Grid-to-surface observation verification

Fig. 4 shows plots of the 10-m wind speed, 2-m temperature, and 2-m specific humidity for the 0-48 h forecasts from the operational Eta, the parallel Eta, and the verifying observations. The value plotted is the average value from surface stations which are collocated with hourly station profile output from the model forecast. These were computed for 49 12Z cycles between 7 August and 24 September 1996. The number of accumulated stations plotted should be divided by the number of cycles to get the number of verifying surface observations at each forecast hour.

The 2-m temperature plot (Fig. 4a) shows excessive daytime warming by 1-2 K in the operational Eta which was corrected in the parallel run. However, the tendency for cooler than observed early morning temperatures in the operational Eta was still seen in the parallel Eta. Although both Eta runs showed a decrease with forecast hour in the specific humidity (Fig. 4b) the parallel Eta was closer to the observations during the first 36 hours of the forecast. Neither Eta model run was able to simulate the weaker 10-m wind speeds at night (Fig. 4c).

5. REFERENCES

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6. FIGURE CAPTIONS

Figure 1. Observed (solid) and 24-h forecast (dashed) soundings from a) the operational Eta model and b) the parallel Eta model at Topeka, Kansas valid at 0000 UTC 4 September 1996. Lines above the figure show forecast and observed lifted index, CAPE, and convective inhibition, respectively. Wind profiles for forecast (left) and observed (right) soundings, respectively.

Figure 2. Same as Fig. 1, but for observed and 12-h forecasts at Topeka, Kansas valid at 1200 UTC 4 September 1996.

Figure 3. a) Bias scores and b) equitable threat scores for 24-h forecast precipitation for the operational Eta (ERLY ETA) and the parallel Eta (EDAS PARA) from 3 August - 26 September 1996.

Figure 4. Average hourly forecast of a) 2-m temperature, b) 2-m specific humidity and c) 10-m wind speed from surface observations (solid line), the operational Eta (dash-dot line) and the parallel Eta (dashed line). Values from an average of 49 (1200 UTC only) cycles from 7 August - 24 September 1996.